STABILITY OF SLOPES IN IRON ORE MINES

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Mining Engineering

By

BHAGABAN MARNDI

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DEPARTMENT OF MINING ENGINEERING

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Under The Guidance of

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CERTIFICATE

This is certify that the thesis entitled "**Stability of Slopes in Iron Ore Mines**" submitted by Sri Bhagaban Marndi, Roll No.107MN018 in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute Of Technology, Rourkela (Deemed University) is authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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CONTENTS

ABSTRACT

Slope stability analysis is important in any opencast iron ore mine. A failure of slope in a working area of mine can give rise a significant economic losses and safety impact. The fundamental failure modes are varied and complex. Such mechanisms are governed by engineering geology condition of rock mass which are almost always unique to a particular site.
Using the FLAC/Slope software stability of slope is analysis. The work was aimed at study of stability of slopes using numerical modelling, at the same time study the different failure mechanism. The purpose of this project is to learn and assess this FLAC/Slope software. As the study of the software is easy, it can be concluded that it is user-friendly. Based on parametric studies it can be concluded that slope angle plays a major role on slope stability.
Safety factor varied from 0.63 to 1.37 for the depth of 10 m to 250 m for the slope angle of 45 degrees. It showed that with the increase in height of the bench or depth of the mine safety factor of the bench decreases indicating less stability of the concerned slope. At the depth of 100 m, the safety factor was found to be exceeding 1.2 for slope angle less than 35 degrees. Therefore, it is recommended to maintain the overall slope angle not steeper than 35 degrees, in the hypothetical mine conditions assumed in the project.

At the depth of 150m, factor of safety is 1.02, and 1.01 for the slope angles of 35 degree and 40 degrees, respectively. This indicated that the slope may be maintained with more than 1.0 safety factor at flatter than 40 degree, ensuring continuous monitoring of the stability of slope through observational approaches. It is recommended that for improving the reliability of model results, calibrations of models with actual field conditions may be taken of through piezometric monitoring and measurement of slope moments in varying geomining condition at different mine sites

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

CHAPTER: 01

INTRODUCTION

The slope stability analyses are performed to assess the safe and economic design of a slope in open pit mining. The objective of the slope stability analysis are finding endangered areas, investigation of potential failure mechanism, determination of slope sensitivity to different triggering mechanism, designing of optimal slopes with regard to safety, reliability and economics.

In large open pit mines, which reach diameters of kilometres and depths of several hundred meters, a difference of a degree or two in pit wall angle can mean millions of rupees in gained or lost ore. Even for mining and quarrying operations of more model size, depending on configuration of the resources and thickness of overburden, slope angle affects to a greater or lesser extent the stripping ratio and hence mining profits.

Successful design of slope requires geological information and site characteristics, e.g. slope geometry, properties of soil/rock, groundwater condition, alternation of materials by faulting, joint or discontinuity system, movement and tension in joints.

Before the computer age stability analysis was performed graphically or using hand-held calculator. Limit equilibrium is the simple solution method most commonly used, but it can become inadequate if the slope fails by complex mechanism. In these cases more sophisticated numerical modelling technique should be utilised.

Design of a final pit limit is thus governed not only by the ore grade distribution and the production cost, but also by the overall rock mass strength and stability.

1.1 Objective

The main objective of the study is to study the stability of slope using numerical modelling with varying depth and angle of slope in iron ore mining.

CHAPTER 2

LITERATURE REVIEW

CHAPTER: 02

LITERATURE REVIEW

In the geo technical field, stability analyses aim to support the safe and functional design of rock and soil slopes. Preliminary analyses can be carried out in order to determine the critical parameter of work stability. Parametric analyses allow one to asses physical and geometrical problem parameter influence on the slope stability.

A rock and soil slope stability analysis allows one to evaluate:

1. The optimal staged excavation or construction time sequence determination;
2. The role, which design parameters such as slope angle and excavation or embankment height, play in the work stability;
3. Consolidation work such as retaining walls, drainage system or rock bolting, which can stabilize slope.

2.1 FACTORS AFFECTING SLOPE STABILITY

Slope failures of different types are affected by the following factors:

2.1.1 Slope Geometry

Slope geometry is the important factor which affects the slope stability. The basic geometrical slope design parameters are bench height, overall slope angle and area of failure surface. Stability of slope decreases with increases in height and slope angle. The overall angle increases the possible extent of the development of the any failure to the rear of the crests increases and it should be considered so that the ground deformation at the mine peripheral area can be avoided. Generally overall slope angle of 45° is considered to be safe by Directorate General of Mines Safety (DGMS). The curvature of the slope has profound effect on the instability and therefore convex section slopes should be avoided in the slope design. Steeper and higher the height of slope less is the stability.

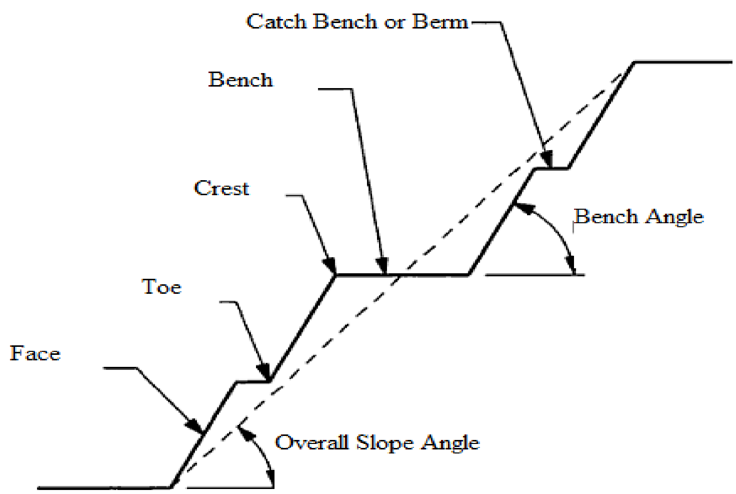

Figure 1.1: **Diagram showing bench angle, face, slope angle, toe and crest.**

2.1.2 Geological Structure

The main geological structure which affect the stability of the slopes in the open pit mines are:

1. Amount and direction of dip
2. Intra-formational shear zones
3. Joints and discontinuities
4. Faults

Instability of rock slope may occur by failure along pre-existing structural discontinuity, by failure through intact material or by failure along a surface formed partly along discontinuity and partly through intact material. Instability may occur if the strata dip into the excavations. Localized steepening of strata is critical for the stability of the slopes. Stability is hampered if a clay band comes in between the two rock bands. Bedding planes and Joints also provide surfaces of weakness.

The slope Stability is dependent on the shear strength available along such surface, on their orientations in relation to the slope and water pressure action on the surface. These shear strength that can be mobilized along joint surface depending on the functional properties of the surface and the effective stress which are transmitted normal to the surface. Joints can create a situation where a combination of joint sets provides a cross over surface.

2.1.3 Lithology

The rock materials forming a large pit slope determines the rock mass strength modified by discontinuities, folding, faulting, old workings and weathering. Low rock mass strength is characterized by ravelling, circular; and rock fall instability like the formation of slope in massive sandstone restricts stability. Pit slopes having soil alluvium or weathered rocks at the surface have low shearing strength and the strength gets further reduced if water seepage takes place through them. These types of slopes must be flatter.

2.1.4 Ground Water

It causes the following:

a) Alters the cohesion and frictional parameters and

b) Reduce the normal effective stress

Ground water causes increased up thrust and driving water forces and has adverse effect on the stability of the slopes. Chemical and Physical effect of pure water pressure in joints filling material can thus alter the cohesion and friction of the discontinuity surface. Physical effects of providing uplift on the joint surface, reduces the frictional resistances. This will reduce the shearing resistance along the potential failure plane by reducing the effective normal stress acting on it. Physical and the chemical effect of the water pressure in the pores of the rock cause a decrease in the compressive strength particularly where confining stress has been reduced.

2.1.5 Mining Method and Equipment

Basically there are four methods of advance in open cast mines. They are:

(a) Strike cut- advancing down the dip

(b) Strike cut- advancing up the dip

(c) Dip cut- along the strike

(d) Open pit working

The use of dip cuts with advance on the strike reduces the time and length that a face is exposed during excavation. Dip cuts with advance oblique to strike may often use to reduce the strata dip in to the excavation. The Open pit method are used in steeply dipping seams, because of the increased slope height are more prone to large slab/buckling modes of failure. Dip cut generally offer most stable method of working but it suffers from restricted production potential. In circular failure cases spoil dumps are more pronounced. Mining equipment which piles on the benches of the open pit mine gives rise to the increase in surcharge, which in turn increases the force which tends to pull the slope face downward and thus instability occurs.

2.1.6 Dynamic Forces

Vibration, Blasting, and shear stresses effects are increased momentarily as a result dynamic acceleration of material and thus increases the stability problem in the slope face. It causes the fracturing of rocks and ground motion.

Blasting is a primary factor governing the maximum achievable bench face angles. The effects of careless or poorly designed blasting can be very significant for bench stability, as noted by Sage (1976) and Bauer and Calder (1971). Besides blast damage and back break which both reduce the bench face angle, vibrations from blasting could potentially cause failure of the rock mass. For small scale slopes, various types of smooth blasting have been proposed to reduce these effects and the experiences are quite good (e.g. Hoek and Bray, 1981). For large scale slopes, however, blasting becomes less of problem since back break and blast damage of benches have negligible effects on the stable overall slope angle. Furthermore, the high frequency of the blast acceleration waves prohibit them from displacing large rock masses uniformly, as pointed out by Bauer and Calder (1971). Blasting-induced failures are thus a marginal problem for large scale slopes.

Seismic events, i.e., low frequency vibrations, could be more dangerous for large scale slopes and several seismic-induced failures of natural slopes have been observed in mountainous areas.

Together with all these causes external loading can also plays an important role when they are present as in case of surcharge due to dumps on the crest of the benches. In high altitude areas, freezing of water on slope faces can results in the build-up of ground water pressure behind the face which again adds up to instability of the slope.

2.1.7 Cohesion

Cohesion is the characteristic property of a soil or rock that measures how well it resists being deformed or broken by gravity force. In soils/rocks true cohesion is caused by electrostatic forces in stiff over consolidated clays, cementing by $Fe2O3$, $CaCO3$, NaCl, etc and root cohesion.
However the apparent cohesion is caused by pore pressure and negative capillary pressure response during untrained loading. Slopes which having rocks/soils with less cohesion tend to be less stable.

The factors that strengthen cohesive force are as follows:

a. Friction
b. Stickiness of particles can hold the soil grains together. However, being too wet or too dry can reduce cohesive strength.
c. Cementation of grains by calcite or silica deposition can solidify earth materials into strong rocks.
d. Man-made reinforcements can prevent some movement of material.

The factors that weaken cohesive strength are as follows:

a. High water content can weaken cohesion because abundant water both lubricates (overcoming friction) and adds weight to a mass.
b. Alternating expansion by wetting and contraction by drying of water reduces strength of cohesion, just like alternating expansion by freezing and contraction by thawing. This repeated expansion is perpendicular to the surface and contraction vertically by gravity overcomes cohesion resulting with the rock and sediment moving slowly downhill.
c. Undercutting in slopes
d. Vibrations from earthquakes, sonic booms, blasting that create vibrations which overcome cohesion and cause mass movement.

2.1.8 Angle of Internal Friction

It is the angle, measured between the normal force and resultant force that is attained when failure just occurs in response to a shearing stress. Its tangent is the coefficient of sliding friction. It is a measure of the ability of a unit of rock or soil to withstand a shear stress. Angle of internal friction is affected by particle roundness and particle size. Lower roundness or larger median particle size results in larger friction angle. It is also affected by quartz content. The sands with less quartz contained greater amounts of potassium-feldspar, plagioclase, calcite, and/or dolomite and these minerals generally have higher sliding frictional resistance compared to that of quartz. Angle of internal friction, can be determined in the laboratory by the Direct Shear Test or the Triaxial Shear Test.

2.2 GENERAL MODES OF SLOPE FAILURE IN ROCK MASSES

There are four primary modes of slope failure in rock masses. These are planar failure, rotational failure, wedge failure and toppling failure.

2.2.1 Planar failure

In planar failure (fig 2.1), the mass progresses out or down and out along a more or less planar or gently undulating surface. The movement is commonly controlled structurally by surface weakness, such as faults, joints, bedding planes, and variation in shear strength between layers of bedded deposits, or the contact between the firm bed rock and overlying weathered rock.

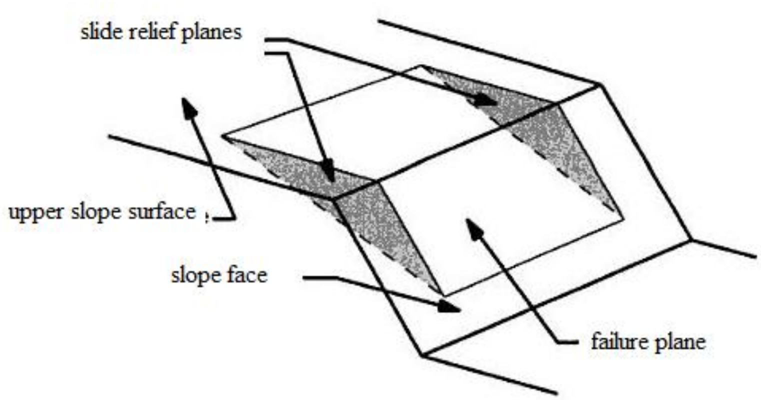

Figure 2.1 Planar Failure Mode

In order for the likelihood of failure to exist, the following condition must be met:

- The strike of the plane of weakness must be within ±20 degree of the strike of the crest of the slope.
- The toe of the failure plane must daylight between the toe and the crest of the slope.
- The dip of the failure plane must be less than the dip of the slope face , and the internal angle of friction for the discontinuity must be less than the dip of the discontinuity (Hoek and Bray 1981)

2.2.2 Rotational failure

The most common examples of rotational failures are little-deformed slumps, which are slide along surface of rupture that is curved concavely upward. In slumps the movement is more or less rotational about an axis that is parallel to the slope (figure 2.2).in the head area movement may be almost wholly downward, forming a near vertical scrap, and have a little apparent rotation; however the top surface of the slide commonly tilts backward away from the pre-existing slope face , thus indicating rotation. A purely circular failure surface on a rotational failure is quite rare because frequently the shape of the failure surface is controlled by the presence of pre-existing discontinuities such as faults, joints, bedding, shear zones, etc.

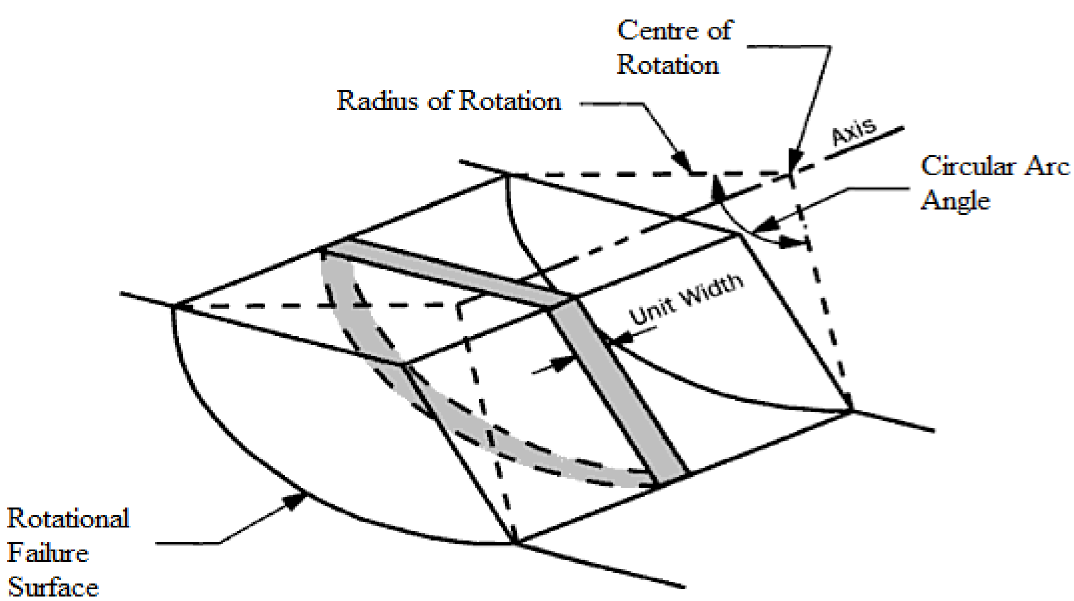

Figure 2.2 Rotational Failure Mode

2.2.3 Wedge failure

The possibility of the wedge failure exists where two discontinuities strike obliquely across the slope face and their line of intersection daylight in the slope face (figure 2.3).The wedge of rock resting on these discontinuities will slide down the line of intersection provided that

- The inclination of the line of intersection is significantly greater than the angle of internal friction along the discontinuities
- The plunge of the line of intersection daylights between the toe and the crest of the slope.

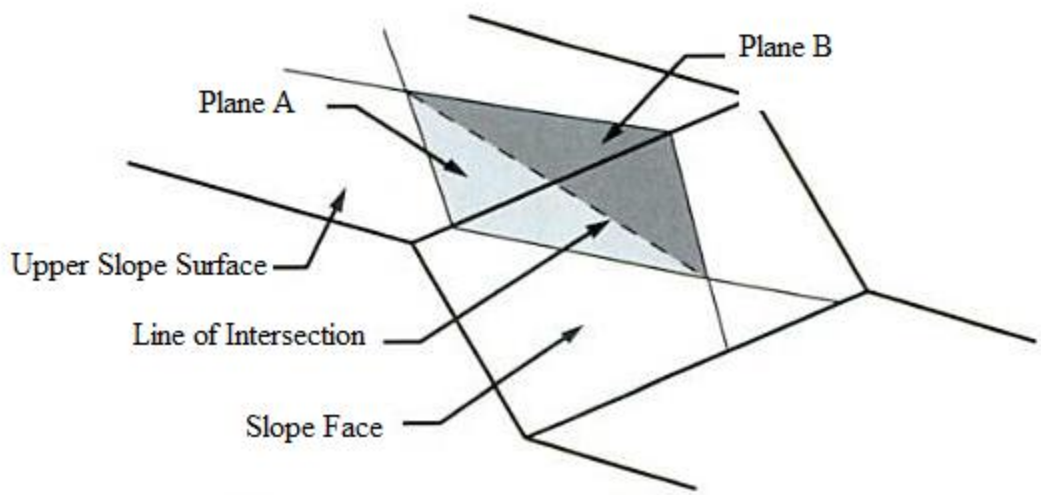

Figure 2.3 Wedge Failure Mode

2.2.4 Toppling failure

Toppling failure occurs when the weight vector of block of rock resting on an inclined plane falls outside the base of the block. This type of failure may occur in undercutting beds (figure 2.4).once they are disturbed the system may collapse or this failure has been postulated as the cause of several failures ranging from small to large. This type of failure generally occurred when the hill slopes are very steep.

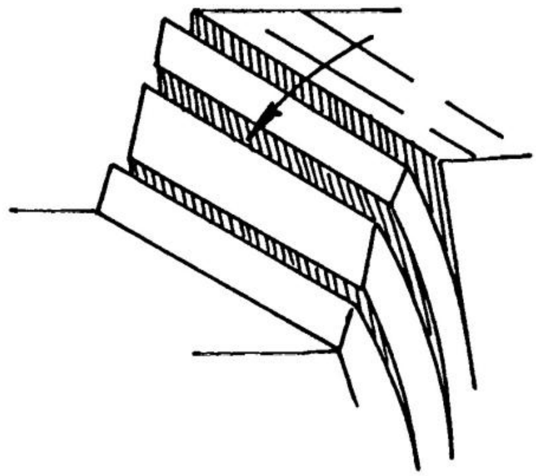

Figure 2.4 Toppling Failure

2.**3 FACTOR OF SAFETY**

The definition of factor of Safety (FOS) is expressed as:

a) F_r/F_d Resisting Force/ Driving Force
b) M_r/M_d Resisting Moment/Driving Moment
c) H_c/H Critical Height /Slope Height
d) s/τ Available Shear Stress /Shear Stress at Equilibrium

Table 2.1 Guidelines for Equilibrium of a Slope

Factor of Safety	Details of Slope
<1.0	Unsafe
1.0-1.25	Questionable Safety
1.25-1.4	Satisfactory for Routine cuts and fills. Questionable for Dams, or where failure would be catastrophic
>1.4	Satisfactory for Dams

The required factor of safety depends on the consequences of losses in terms of property, lives and cost of repair in the event of slope failure. FOS is also depending on the reliability of design parameter.

For highly unlikely loading condition, factor of safety can be as low as 1.2 -1.25 even for dams. e.g. situation based on seismic effects, or where there is rapid draw down of the water level in reservoir.

According to Stephen Martel (2002), the main points of the factor of safety are:

1. The safety factor cannot be measured in the field
2. The safety factor is model-dependent
3. A factor of safety higher significantly greater than the one desirable because uncertainty regarding the geological condition and pore pressure variability.

2.4. NUMERICAL MODELLING

Numerical modelling techniques gives a solution to problems which cannot be solved by conventional methods, e.g., material anisotropy, non-linear behaviour, complex geometry in situ stresses. Advance in computing power and the availability of relatively inexpensive commercial numerical modelling codes means that the simulation of potential rock slope failure mechanism could, and in many cases should, form a standard component of rock slope investigation.

Analysis by numerical method allows for material deformation and failure; creep, dynamic loading, modelling of pore pressures, assessing effects of parameter variations etc. However, numerical modelling has some limitations. For example, input parameters are not usually measured and availability of these data is generally poor. Analysis must be executed by well trained user with good modelling practise. User also should be aware of boundary effects, meshing errors, and hardware memory and time restrictions. Numerical methods used for slope stability analysis can be divided into three main groups: continuum, discontinuum and hybrid modelling.[38]

Table2.2 Numerical Method of Analysis

Analysis Method	Critical Input Parameters	Advantages	Limitations
Continuum modelling (e.g. finite element, finite difference method)	Representative slope geometry; constitutive criteria (e.g. elastic, elasto-plastic, creep etc.) groundwater characteristics; shear strength of surface; in situ stress state.	Allows for material deformations and failure. Can model complex behaviour and mechanisms. Capability of 3-D modelling. Can model effects of ground water and pore pressure. Able to assess effects of parameter variations on instability. Recent advances in computing hardware allow complex models to be solved on PC's with reasonable run times. Can incorporate creep deformation. Can incorporate dynamics analysis	User must be well trained, experienced and observe god modelling practice. Need to be aware of model/software limitations (e.g. Boundary effects, mesh aspect ratios, symmetry, and hardware memory restrictions). Availability of input data generally poor. Required input parameters not routinely measured. Inability to model effects of highly jointed rock. Can be difficult to perform sensitivity analysis due to run time constraints.
Discontinuum modelling (e.g. distinct element, discrete element	Representative slope and discontinuity geometry; intact constitutive criteria;	Allows for block deformation and movement of blocks relative to each other.	As above, experienced user required to observe good modelling practice.

method)	discontinuity stiffness and shear strength; groundwater characteristics; in situ stress state.	Can model complex behaviour and mechanisms (combined material and discontinuity behaviour coupled with hydro mechanical and dynamic analysis). Able to assess effects of parameter variation on instability	General limitations similar to those listed above. Need to be aware of scale effects. Need to simulate representative discontinuity geometry (spacing, persistence, etc.) limited data on joint properties available.
Hybrid/Coupled modelling	Combination of input parameters listed above for stand-alone models.	Coupled finite elements /distinct element models able to simulate intact fracture propagation and fragmentation of jointed and bedded media.	Complex problems require high memory capacity. Comparatively little practical experience in use. Requires ongoing calibrations and constraints

2.4.1 Continuum modelling

Continuum modelling is the best suited for the analysis of slope which are comprised of weak rocks, massive, intact rock, and soil-like or heavily fractured rock masses. Most continuum codes inappropriate a facility for including discrete fracture such as fault and bedding planes but are in appropriate for the analysis of blocky mediums. The continuum approaches used in rocks slope stability include the finite-element methods and finite-difference. In latest year the majority of published continuum rock slope analysis has used the 2-D finite-difference code, FLAC. This code allow a wide choice of constitutive models to characterize the rock mass and incorporates time dependent behaviour, coupled hydro-mechanical and dynamic modelling. 2-D continuum codes assume plane strain conditions and frequently not valid in inhomogeneous rock slope with varying structure, lithology and topography. The recent advance of 3-D continuum codes such as FLAC3D and VISAGE enables the engineer to undertake 3-D analysis of rock slopes on a desktop computer.

Although two dimension and 3-D continuum codes are extremely useful in characterizing rock slope failure mechanism it is the responsibility of the engineer to verify whether they are representative of the rock mass under consideration. Where rock slope comprises of the multiple joint sets, which control the mechanism of failure, then a discontinuum modelling approach may be considered more appropriate.

2.4.2 Discontinuum Modelling

Discontinuum methods treat the rock slope as a discontinuous rock mess by considering it is an assemblage of deformable or rigid block. The analysis includes sliding along and opening/closure of rock discontinuities controlled principally by the joint normal and joint shear stiffness. Discontinum modelling constitutes the commonly applied numerical approach to rock slope analysis, the distinct element method is the most popular method. Distinct element codes such as UDEC use a force displacement law specifying interaction between the deformable joint bounded blocks and newton's second law of motion, providing displacement induced within the rock slope.

2.4.3 Hybrid Techniques

Hybrid techniques are increasingly being used in rock slope analysis. This may include the combined analysis using limit equilibrium stability analysis and finite element ground water flow and stress analysis such as adopted in the GEO-SLOPE site of software. Hybrid numerical models have been used for a considerable time in underground rock engineering including coupled boundary/finite element and coupled boundary/distinct element solutions. Recent advances include coupled particle flow and finite difference analyses using FLAC3D and PF3D. These hybrid techniques already show significant potential in the investigation of such phenomena as piping slope failures, and the influence of high groundwater pressure on the failure of weak rock slopes. Coupled finite /distinct-element codes are now available which incorporate adaptive remeshing. This coupled with a discrete –element model able to model deformation involving joints. If the stresses with in the rock slope exceed the failure criteria with in the finite element model a crack is initiated. Remeshing allows the propagation of the cracks through the finite element mesh to be simulated. Hybrid codes with adaptive remeshing routines, such as ELFEN, have been successfully applied to the simulation of intense fracturing associated with surface mine blasting, mineral grinding, retaining wall failure and underground rock caving.

2.5 GENERAL APPROACH OF FLAC

The modeling of geo-engineering processes involves special considerations and a design philosophy different from that followed for design with fabricated materials. Analyses and designs for structures and excavations in or on rocks and soils must be achieved with relatively little site-specific data, and an awareness that deformability and strength properties may vary considerably. It is impossible to obtain complete field data at a rock or soil site.

Since the input data necessary for design predictions are limited, a numerical model in geomechanics should be used primarily to understand the dominant mechanisms affecting the behaviour of the system. Once the behaviour of the system is understood, it is then appropriate to develop simple calculations for a design process.

It is possible to use FLAC directly in design if sufficient data, as well as an understanding of material behaviour, are available. The results produced in a FLAC analysis will be accurate when the program is supplied with appropriate data. Modellers should recognize that there is a continuous spectrum of situations, as illustrated in Figure 2.5, below.

Typical Situation	Complicated geology; Inaccessible; no testing budget	⟷	Simple geology; lots of money spent on site investigation
Data	None	⟷	Complete
Approach	Investigation of mechanism	← Bracket field behaviour by parameter studies →	Predictive (direct use in design)

Figure 2.5 Spectrum of Modelling Situations

The model should never be considered as a "black box" that accepts data input at one end and produces a prediction of behaviour at the other. The numerical "sample" must be prepared carefully, and several samples tested, to gain an understanding of the problem. Table 2.3 lists the steps recommended to perform a successful numerical experiment; each step is discussed separately.

Table 2.3 Recommended steps for numerical analysis in Geomechanics

Step 1	Define the objectives for the model analysis
Step 2	Create a conceptual picture of the physical system
Step 3	Construct and run simple idealized models
Step 4	Assemble problem-specific data
Step 5	Prepare a series of detailed model runs
Step 6	Perform the model calculations
Step 7	Present results for interpretation

2.5.1 Define the Objectives for the Model Analysis

The level of detail to be included in a model often depends on the purpose of the analysis. For example, if the objective is to decide between two conflicting mechanisms that are proposed to explain the behaviour of a system, then a crude model may be constructed, provided that it allows the mechanisms to occur. It is tempting to include complexity in a model just because it exists in reality. However, complicating features should be omitted if they are likely to have little influence on the response of the model, or if they are irrelevant to the model's purpose. Start with a global view and add refinement if necessary.

2.5.2 Create a Conceptual Picture of the Physical System

It is important to have a conceptual picture of the problem to provide an initial estimate of the expected behaviour under the imposed conditions. Several questions should be asked when preparing this picture. For example, is it anticipated that the system could become unstable? Is the predominant mechanical response linear or nonlinear? Are movements expected to be large or small in comparison with the sizes of objects within the problem region? Are there well-defined discontinuities that may affect the behaviour, or does the material behave essentially as a continuum? Is there an influence from groundwater interaction? Is the system bounded by physical structures, or do its boundaries extend to infinity? Is there any geometric symmetry in the physical structure of the system?

These considerations will dictate the gross characteristics of the numerical model, such as the design of the model geometry, the types of material models, the boundary conditions, and the initial equilibrium state for the analysis. They will determine whether a three-dimensional model is required, or if a two-dimensional model can be used to take advantage of geometric conditions in the physical system.

2.5.3 Construct and Run Simple Idealized Models

When idealizing a physical system for numerical analysis, it is more efficient to construct and run simple test models first, before building the detailed model. Simple models should be created at the earliest possible stage in a project to generate both data and understanding. The results can provide further insight into the conceptual picture of the system; Step 2 may need to be repeated after simple models are run.

Simple models can reveal shortcomings that can be remedied before any significant effort is invested in the analysis. For example, do the selected material models sufficiently represent the expected behaviour? Are the boundary conditions influencing the model response? The results from the simple models can also help guide the plan for data collection by identifying which parameters have the most influence on the analysis.

2.5.4 Assemble Problem-Specific Data

The types of data required for a model analysis include:

- details of the geometry (e.g., profile of underground openings, surface topography, dam profile, rock/soil structure);
- locations of geologic structure (e.g., faults, bedding planes, joint sets);

- material behaviour (e.g., elastic/plastic properties, post-failure behaviour);
- initial conditions (e.g., in-situ state of stress, pore pressures, saturation); and
- External loading (e.g., explosive loading, pressurized cavern).

Since, typically, there are large uncertainties associated with specific conditions (in particular, state of stress, deformability and strength properties), a reasonable range of parameters must be selected for the investigation. The results from the simple model runs (in Step 3) can often prove helpful in determining this range, and in providing insight for the design of laboratory and field experiments to collect the needed data.

2.5.5 Prepare a Series of Detailed Model Runs

Most often, the numerical analysis will involve a series of computer simulations that include the different mechanisms under investigation and span the range of parameters derived from the assembled database. When preparing a set of model runs for calculation, several aspects, such as those listed below, should be considered.

I. How much time is required to performare excessive. Consideration should be given to performing parameter variations on multiple computers to shorten the total computation time

II. The state of the model should be saved at several intermediate stages so that the entire run does not have to be repeated for each parameter variation. For example, if the analysis involves several loading/unloading stages, the user should be able to return to any stage, change a parameter and continue the analysis from that stage.

III. Are there a sufficient number of monitoring locations in the model to provide for a clear interpretation of model results and for comparison with physical data? It is helpful to locate several points in the model at which a record of the change of a parameter (such as displacement) can be monitored during the calculation.

2.5.6 Perform the Model Calculations

It is best to first make one or two model runs split into separate sections before launching a series of complete runs. The runs should be checked at each stage to ensure that the response is as expected. Once there is assurance that the model is performing correctly, several data files can be linked together to run a complete calculation sequence. At any time during a sequence of runs, it should be possible to interrupt the calculation, view the results, and then continue or modify the model as appropriate.

2.5.7 Present Results for Interpretation

The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen, or as output to a hardcopy plotting device. The graphical output should be presented in a format that can be directly compared to field measurements and observations.
Plots should clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. The numeric values of any variable in the model should also be readily available for more detailed interpretation by the modeller.
The above seven steps are to be followed to solve geo-engineering problems efficiently

2.6. FLAC/SLOPE – A NUMERICAL MODEL

FLAC/SLOPE uses the graphical interface and it calculates the factor of safety. FLAC is the core of a new, user-friendly code that models slope stability problems under a wide variety of slope condition. These include: arbitrary slope geometries, multiple layers, pore pressure conditions, heterogeneous soil properties, surface loading, and structural reinforcement.

FLAC/SLOPE uses the same calculation method as FLAC with a simplified modelling environment that provides tools and facilities exclusive to slope stability analysis. The result is a code that offers rapid model development, proven analytical capabilities and fast solution reporting.

Tools within the FLAC/SLOPE allow for rapid model development, including

1. Creation of the slope geometry
2. Addition of layers
3. Specification of material either manually or from a database,

4. Positioning a planar or non-planar material interface
5. Location of water table
6. Application of surface loading at any location
7. Installation of structural support such as soil nails or rock bolts

2.6.1 **Summary of Features**

FLAC/Slope can be applied to a wide variety of conditions to evaluate the stability of slopes and embankments. Each condition is defined in a separate graphical tool.

1. The creation of the slope boundary geometry allows for rapid generation of linear, nonlinear and benched slopes and embankments. The Bound tool provides separate generation modes for both simple slope shapes and more complicated non-linear slope surfaces. A bitmap or DXF image can also be imported as a background image to assist boundary creation.

2. Multiple layers of materials can be defined in the model at arbitrary orientations and nonuniform thicknesses. Layers are defined simply by clicking and dragging the mouse to locate layer boundaries in the Layers tool.

3. Materials and properties can be specified manually or from a database in the Material tool. At present, all materials obey the Mohr-Coulomb yield model, and heterogeneous properties can be assigned. Material properties are entered via material dialog boxes that can be edited and cloned to create multiple materials rapidly.

4. With the Interface tool, a planar or non-planar interface, representing a joint, fault or weak plane, can be positioned at an arbitrary location and orientation in the model. The interface strength properties are entered in a properties dialog; the properties can be specified to vary during the factor-of-safety calculation, or remain constant.

FLAC/Slope is limited to slope configurations with no more than one interface. For analyses which involve multiple (and intersecting) interfaces or weak planes, full FLAC should be used.

5. An Apply tool is used to apply surface loading to the model in the form of either a real pressure (surface load) or a point load.

6. A water table can be located at an arbitrary location by using the Water tool; the water table defines the paretic surface and pore pressure distribution for incorporation of effective stresses and the assignment of wet and dry densities in the factor-of-safety calculation.

7. Structural reinforcement, such as soil nails, rock bolts or geotextiles, can be installed at any location within the model using the Reinforce tool. Structural properties can be assigned individually for different elements, or groups of elements, through a properties dialog.

8. Selected regions of a FLAC/Slope model can be excluded from the factor-of-safety calculation.

2.6.2 Analysis Procedure

FLAC/SLOPE is specifically designed to perform multiple analysis and parametric studies for slope stability projects. The structure of the program allows different models in a project to be easily created, stored and accessed for direct comparison of model results. A FLAC/SLOOPE analysis project is divide into four stages, which is models stage, solve stage and plot stage.

Model stage

In this stage, model can be created, named and listed in tabbed bar in a project. New model can be added to the tabbed bar or deleted from it at any time in the project study. Model can also be restored from previous and added to the current project.

Build stage

For specific model, the slope conditions are defined in the build stage. This includes:

- Changes to the slope geometry,
- Addition of layers
- Specification of materials and weak plane
- Application of surface loading
- Position of water table
- Installation of reinforcement

Also, spatial regions of the model can be excluded from the factor of safety calculation.

Solve stage

In this solve stage, factor of safety is calculated. The resolution of the numerical mesh is selected first (coarse, medium, fine and user-specific) and then the factor of safety calculation is performed.by default, the material cohesion and frictional angle are used. The different parameter can be selected for inclusion in the strength reduction approach to calculate the safety factor.

Plot Stage

After the solution is complete, several output selection are available in this plot stage for displaying the failure surface and recording the results. Models results are available for subsequent access and comparison to other models in the project. All models created within a project, along with their solution, can be saved in different format, the project files can be easily restored and results viewed at alter time.

CHAPTER 3

CASE STUDY

CHAPTER: 03

CASE STUDY

3.1 INTRODUCTION

The Bellary-Hospet-Sandur sector in Bellary district is a major producer of iron ore in the Karnataka. At present around 40-45 million tones of ore per year is being produced from these mines by opencast method. As the demand for the ore extracted in the district is high, about 90 per cent of it is exported through ports in Chennai, Visakhapatnam and Tadadi in the east and Karwar, Mangalore and Belikeri in the west. These deposits are being exploited by several mining companies over many years by raising high grade iron ore for meeting domestic and international markets. The total estimated reserves of iron ore in this sector is around 700-750 million tones..

Figure 3.1 Overview of SVK Iron Ore Mine

There are five major iron bearing hill ranges in the entire area, which are named as NEB-Thimmappanagudi, Donamalai, Devadgari, Kumaraswamy and Ramandurga. Most of hill ranges are having rugged topography having fairly dense vegetation. The height of the hill ranges varied between 886 m to 1005m, with steep slopes. The iron ore occurs in powdery and lumpy form associated with laterite, BHQ, shale, phyllites and weathered / altered gabbros.

3.2 GEOTECHNICAL INVESTIGATION

The purpose of the geotechnical investigation is basically addressed broadly to understand the mechanism of failure of the benches, which may cause further slope instability during the progress of future mining operations.

A bench collapse in the form of a slide took place in the hangwall portion at SVK Vyasankare Mines, which has caused concern for the safety and stability of the existing benches. The slide took place in the 7th bench of the main pit, joining two benches forming a high wall of 12m in height

The slide might have occurred in a contact zone between the phyllite/shale and the main ore body. The phyllite/ shale contact is having thin coating of serpentinite which acted as a soapy layer during the process of sliding. It is well exposed at places along the strike length of the ore body. There are several mines operating in similar geo-mining conditions in the Hosper-Sandur belt. Geological map of Hospet area is presented in Figure 3.1 However, no such localized bench failures or slides were reported earlier. The cause of such local bench failures are of concern in the overall interest of mine management for maintaining safety and production.

A preliminary site investigation of the study area has revealed that the structural complexity of the area in which the present mining operations are being conducted. There appears to be the contribution of small scale drag folds, which formed synformal structure, plunging gently to NNW, which might have caused local instability of the benches. Contact zones which are dipping at 80 degree are with a width of 1 to 2.5m.

3.3 MINE GEOLOGY

The typical geological profile of the area comprise of Laterite/ soil cover, BHQ (Banded Hematite Quartzite), Iron ore, Shale/ Phyllites and Meta-volcanics.

The dips of the formations are steep 85º NE to near vertical. The general strike direction of the ore body is NW-SE. The mineable strike length is around 720m with the width of the ore body varying from 25m to 102m.

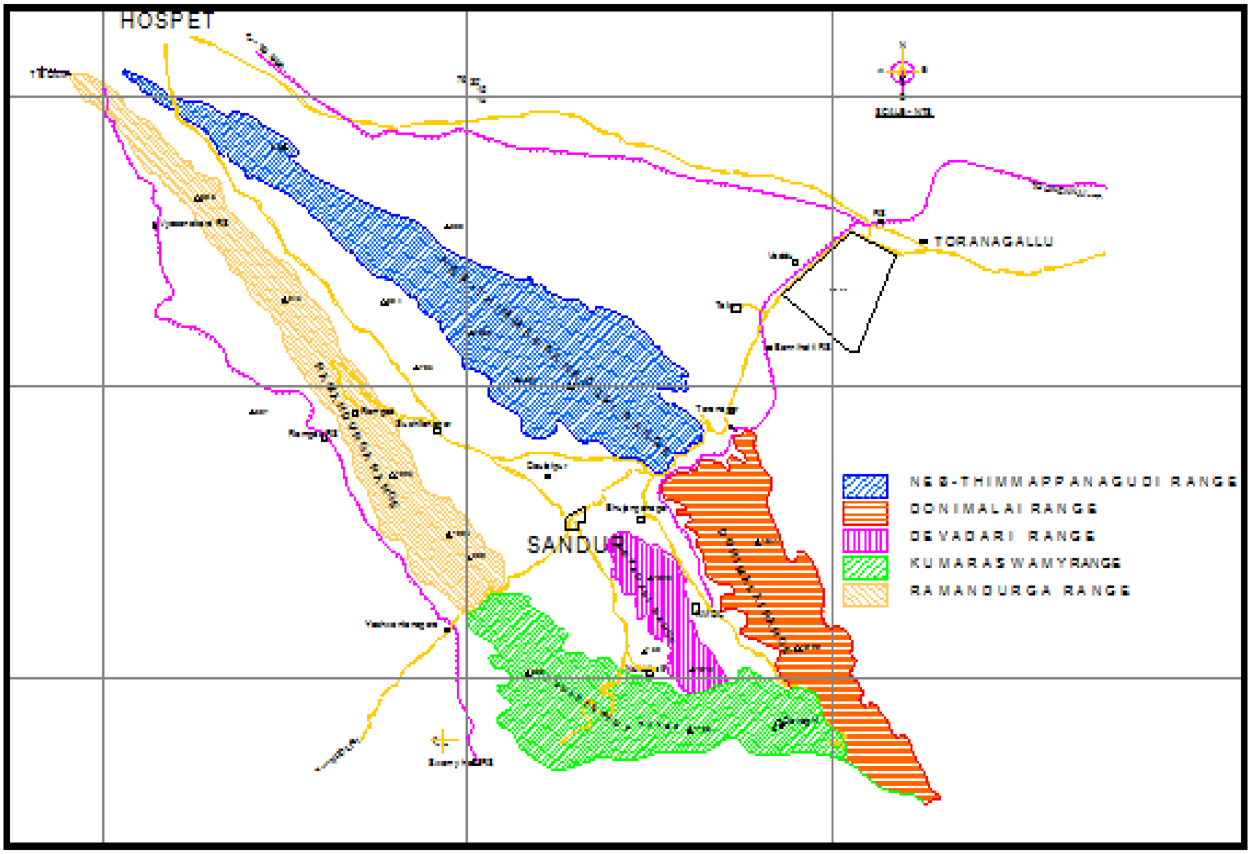

Figure 3.2 Geological Map of Hospet Area

In the north wall, there are three iron ore bands exposed with intermediate barren partings of low grade or sub grade BHQ formations. Whereas, at the bottom of the present mine workings, the three ore bands joined together forming a wide ore body.

There are several intercalations of small phyllite/ shale bands as seen from the exposed/ worked out benches. These phyllites/ shales are highly weathered and sometimes altered at places. Surface staining of sertpentinsed material having 2cm to 4cm in thickness has been observed having smoothed planar or concave in- fill material. This acts as a slip plane along the contact zone, which may likely to accelerate the sliding process. The failure type and mode of failure will be analyzed based on the stereonet analysis followed by kinematic analysis of slope.

Table 3.1 Summary of Joint Properties of Bench No1.

S.No.	Rock type	No. of joint sets	Strike range	Dip range	In-fill material	Remarks
1	Shale	3	N55E to N64E	60NE to 68 NE	Intercalations of altered material	Low shear Strength, crumbled
2	Powdery ore	2	N64E N74E	54E-64NE	friable	Soft, powdery
3	Gabbro	3	N54E-N82 E	64 NE-N78NE	weathered	Crumbled and weak rock mass
4	Sub grade BHQ	3	N54 W-N	68NE		Laminated
5	Lumpy Ore	3	N38 E- N 72W	42NE-NE88	-	Hard, compact

3.4 **PHYSICO-MECHANICAL PROPERTIES**

For numerical modelling and analysis the physic-mechanical properties is requires. Table 3.3 shows the phisico –mechanical properties of rock samples related to various materials in the mine.

Table 3.2 Major and Minor Principal Stresses of Rock Samples Related To Section-A, B, C, and D

Type of rock	Sample-1		Sample-2		Sample-3	
	σ_1	σ_3	σ_1	σ_3	σ_1	σ_3
A	$65.6*10^5$ Pa	$2.0*10^5$ Pa	$68.8*10^5$ Pa	$4.0*10^6$Pa	$76.2*10^5$ Pa	$6.0*10^5$ Pa
B	$14.*10^5$ Pa	$2.0*10^5$ Pa	$22.2*10^5$ Pa	$4.0*10^5$ Pa	$33.4*10^5$ Pa	$6.0*10^5$ Pa
C	$33.4*10^5$ Pa	$2.0*10^5$ Pa	$46.4*10^5$ Pa	$4.0*10^5$ Pa	$47.4*10^5$Pa	$6.0*10^5$ Pa
D	$48.7*10^5$ Pa	$2.0*10^5$ Pa	$45.8*10^5$ Pa	$4.0*10^5$ Pa	$49.14*10^5$ Pa	$6.0*10^5$ Pa

Table 3.3 physic-mechanical properties of rock samples related to rock types A, B, C and D

Section	density	Tensile Strength	Cohesion	Internal Friction
A	2532 Kg/m^3	3785kPa	$9*10^5$Pa	39^0
B	4300 Kg/m^3	4969kPa	$3*10^5$Pa	33^0
C	4602 Kg/m^3	5816kPa	$5.5*10^5$Pa	45^0
D	3911 Kg/m^3	5621kPa	$10.5*10^5$ Pa	30^0

A-Phylite/Shale, B and C- Iron Ore, D-Banded Haematite Quartzite (BHQ)

3.5 PARAMETRIC STUDIES

Parametric studies were conducted through numerical models (FLAC/SLOPE) to study the effect of depth (10m-250m). Pit slope angle was varied from 35° to 55º at an interval of 5º.

Typical model developed by FLAC/Slope with varying depth and slope angle

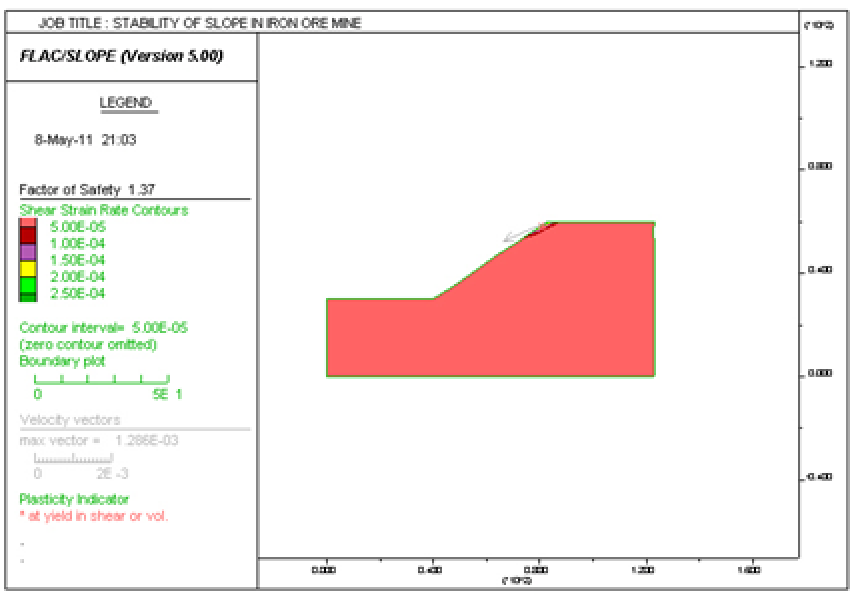

Figure 3.3 Typical model with Slope Angle = 35º, Depth = 30m, Factor of Safety = 1.37

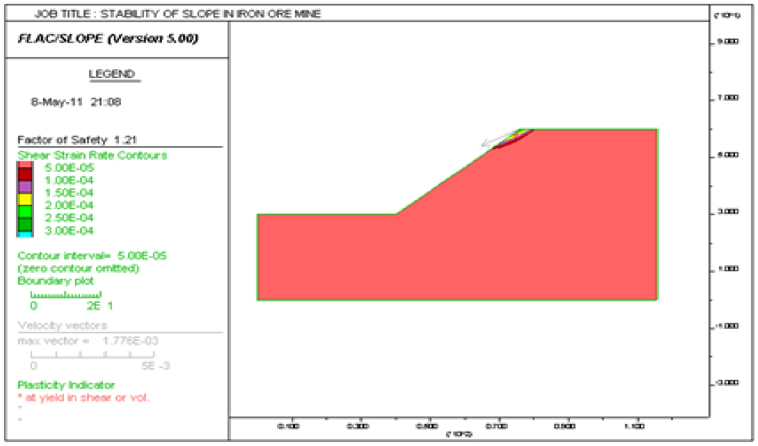

Figure 3.4 Typical model with Slope Angle = 40º,Depth= 30m, Factor of Safety= 1.21

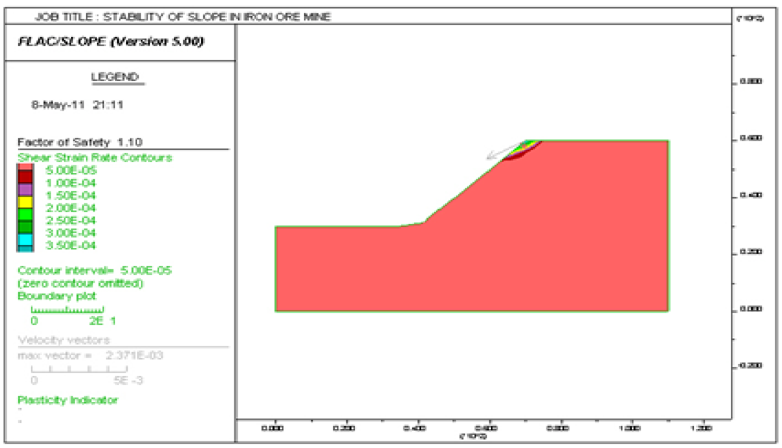

Figure 3.5 Typical model with Slope Angle = 45º, Depth= 30m, Factor of Safety= 1.10

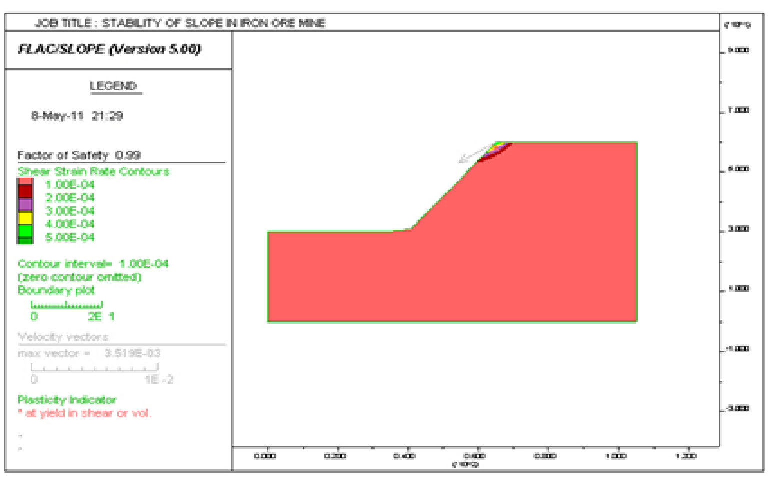

Figure 3.6 Typical model with Slope Angle = 50º,Depth = 30m,Factor of Safety= 0.99

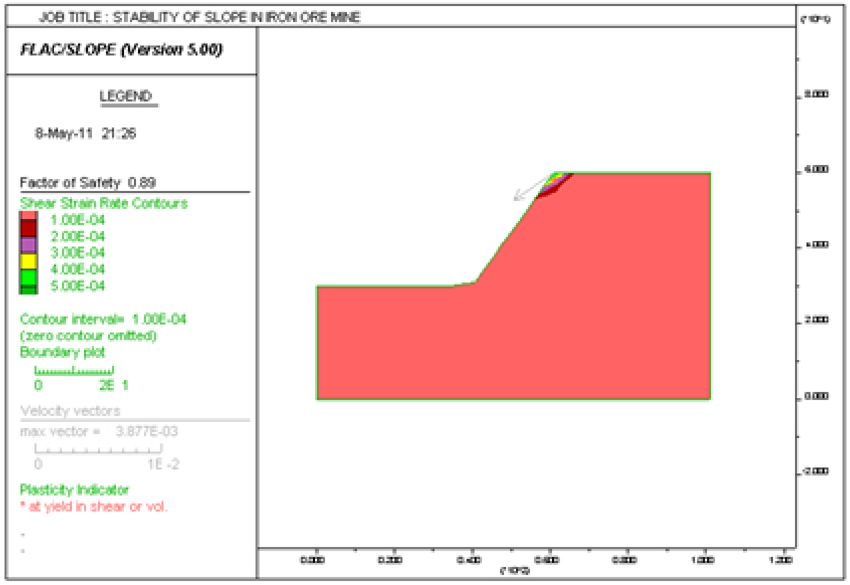

Figure 3.7 Typical model with Slope Angle= 55º. Depth= 30m, Factor of Safety= 0.89

Table 3.4 safety factor for various depth and slope angle

Sl.No.	Depth(m)	Slope Angle(º)	Factor of Safety
1	10	35	1.64
		40	1.48
		45	1.37
		50	1.32
		55	1.25
2	20	35	1.39
		40	1.23
		45	1.17
		50	1.05
		55	0.96
3	30	35	1.37
		40	1.21
		45	1.10
		50	0.99
		55	0.89

4	40	35	1.33
		40	1.17
		45	1.02
		50	0.94
		55	0.85
5	50	35	1.25
		40	1.07
		45	0.95
		50	0.85
		55	0.79
6	100	35	1.24
		40	1.02
		45	1.00
		50	0.74
		55	0.64
7	150	35	1.02
		40	1.01
		45	0.89
		50	0.67
		55	0.50
8	200	35	0.92
		40	0.83
		45	0.70
		50	0.67
		55	0.48
9	250	35	1.05
		40	0.75
		45	0.63
		50	0.48
		55	0.41

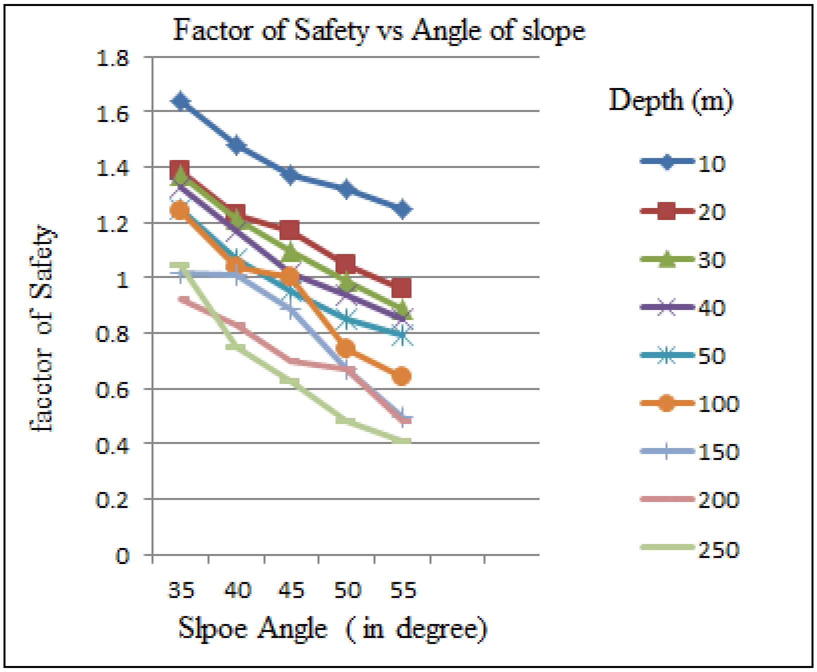

Figure 3.8 Variation of Factor of Safety with Slope Angle for Different Depth

3.6 RESULT AND DISCUSSION

It is observed from the table that as the pit slope angle increases, the factor of safety decreases and the stability of the slope decreases. In total 45 model iterations were carried out, with different set of data on changing the slope angle with the increment of 5 degree from 35 degree to 55 degree to understand the effect on factor of safety. The result of the analysis has indicated that the factor of safety varied from 0.41 to 1.64 with 35 degree to 55 degree slope angles. The factor of safety 1.2 is considered safe.

It was observed that the factor of safety changes with change in the resolution of numerical mesh while running the numerical model FLAC/slope. Factor of safety is quite approximate in coarse mesh while factor of safety converges to the possible value making it more accurate. Factor of safety calculation in coarse mesh as compared to fine and medium mesh is faster. So considering the time availability and requirement of modeller, the suitable mesh has to be selected.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

CHAPTER: 04

CONCLUSION AND RECOMENDATION

Parametric studies were conducted by numerical model FLAC/SLOPE for varying slope angle and depth of the typical mine condition; following are the conclusion and recommendation based on the numerical modelling results.

1. Safety factor varied from 0.63 to 1.37 for the depth of 10 m to 250 m for the slope angle of 45 degrees. It showed that with the increase in height of the bench or depth of the mine safety factor of the bench decreases indicating less stability of the concerned slope.
2. At the depth of 100 m, the safety factor was found to be exceeding 1.2 for slope angle less than 35 degrees. Therefore, it is recommended to maintain the overall slope angle not steeper than 35 degrees, in the hypothetical mine conditions assumed in the project.
3. At the depth of 150m, factor of safety is 1.02, and 1.01 for the slope angles of 35 degree and 40 degrees, respectively. This indicated that the slope may be maintained with more than 1.0 safety factor at flatter than 40 degree, ensuring continuous monitoring of the stability of slope through observational approaches.
4. It is recommended that for improving the reliability of model results, calibrations of models with actual field conditions may be taken of through piezometric monitoring and measurement of slope moments in varying geomining condition at different mine sites.

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